URBAN POLICY BRIEF

UNIVERSITY OF SOUTHERN CALIFORNIA URBAN INITIATIVE

Houses of the Future

Construction by Contour Crafting

Building Houses for Everyone

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USC UNIVERSITY OF SOUTHERN CALIFORNIA

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Urban Initiative Public Policy Briefing

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HOUSES OF THE FUTURE
CONSTRUCTION BY CONTOUR CRAFTING
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URBAN INITIATIVE POLICY BRIEF

Reporting on a study sponsored by the National Science Foundation, the Office of Naval Research, and the USC Urban Initiative

Contour Crafting (CC) is a computer-automated construction technology, invented and developed at USC to deliver rapid production, ease of use, significant reduction of waste, and other substantial cost savings. Not only will CC have a significant impact on the point of delivery, but the whole support structure will be similarly affected by the technology. We anticipate substantial revenues for a wide variety of direct users of the technology and its suppliers. In addition to the enormous economic potential, CC has been designed to deliver improved quality of life, superior safety, and beneficial environmental impact. In this sense, CC will enable the construction of custom-designed, low-cost housing with a level of quality heretofore unobtainable. Further, safety elements inherent in the process will significantly reduce the rate of on-the-job injuries that are so prevalent in the construction industry today, thereby lowering the costs of litigation, insurance, and medical treatment, to say nothing of saving lives. The environmental impact will also be significant through energy savings for construction and the near-elimination of waste product. In the long run, CC will revolutionize the construction industry.

- Fact: It currently takes six to nine months to construct an average house in the US.
  - CC promises custom-designed houses completed in one day.
- Fact: Nearly 30 million U.S. households face cost burdens, overcrowding, and/or space inadequacy. While large cities in developing countries are growing at rates nearing 5% per year, slums and squatter settlements have been growing nearly twice as fast.
  - Imagine dignified and affordable housing constructed for low-income populations.
- Fact: It can take several months or years before disaster victims are placed in permanent housing.
  - Imagine comfortable and livable emergency shelters (not tents) constructed rapidly for long-term use.
- Fact: Construction contributes significantly to harmful emissions and construction of a typical single-family home generates a waste stream of about 3 to 7 tons. Globally, more than 40% of all raw materials are consumed in construction.[1]
  - CC offers construction without waste, noise, dust, or harmful emission.
- Fact: 400,000 workers are seriously injured or killed in construction annually in the US.
  - CC can deliver construction without accidents, injuries, or litigation.
- Fact: Any departure from standard rectilinear design significantly increases the cost of conventional construction.
  - Consider the possibility of new architectural designs for homes, neighborhoods and cities without attendant increases in cost.

What we can only imagine today can be realized in the near future by CC. This revolutionary technology uses modern robotics in combination with a construction tool used since ancient times—the trowel—to build a custom-designed house in a few hours. The multidisciplinary nature of this technology development demands the convening of a substantial portion of the intellectual resources of USC; hence a collaborative team of faculty from the Schools of Engineering, Architecture, Fine Arts, Policy, Planning and Development, and Letters, Arts and sciences are considering the design and implementation issues for CC. A full implementation of the technology will have the potential to significantly improve the urban housing infrastructure in Southern California, the entire nation, and the world, by providing much higher quality construction at much lower cost.

At present, CC would be most useful for emergency reconstruction by disaster and relief agencies working in third world nations devastated by earthquakes, floods, other natural disasters and war. Implementation of this

[1] Measured by weight, which amounts to approximately three billion tons annually.

TABLE 1:

Cost Portion of Conventional Construction	Due to	If Automated by CC
20%-25%	Financing	*Short project length and control of **time to market** will eliminate or dramatically reduce financing cost*
25%-30%	Materials	*No waste in construction*
45%-55%	Labor	*Manual labor will be significantly reduced. Muscle power will be replaced by brain power. Women and elderly workers for the first time will find new job opportunities in construction.*

breakthrough technology in the US is complicated by prevailing policies that regulate labor, zoning, and land costs. Nevertheless, the availability of this new technology has the potential to change the building industry in the US. For Californians, it may provide an emergency solution following a large earthquake.

With national construction-related expenditures currently totaling $300 billion in the public sector and $677 billion in the for-profit sector annually, the potential impact of the USC CC technology is nothing short of astounding. Table 1 above highlights its major benefits.

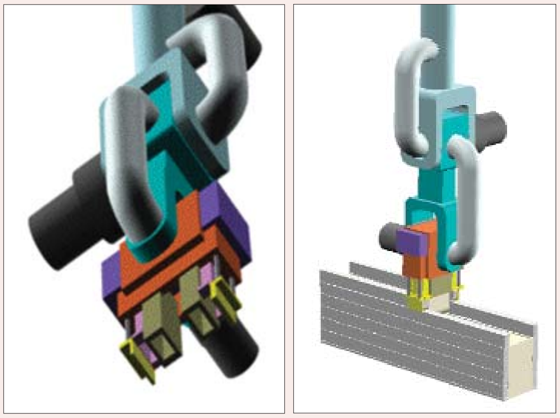
Although residential construction may be the most important application of CC, the technology can be effectively used to fabricate large public art and in extraterrestrial construction. At this point CC seems to be the best candidate for building structures on the Moon and Mars, which are being targeted for human colonization by the end of the current century. A project entitled Lunar Contour Crafting has already started at NASA Marshal Space Flight Center with the target of testing the CC technology on the lunar soil by 2010.

THE CC TECHNOLOGY

Invented at USC, CC is a hybrid fabrication method that combines an extrusion process for forming object surfaces and a filling process to build the object core in layered fashion. As shown in Figure 1, the extrusion nozzle used to create structural elements has multiple outlets, one for each side, and others for the inner (core) of a wall structure. Each side orifice has an adjacent trowel. As the material is extruded, the traversal of the trowels creates smooth (2 micron has been achieved) outer and top surfaces on each layer. The nozzle can be deflected to create non-orthogonal surfaces such as domes and vaults. Co-extrusion of multiple materials is also possible.

FIGURE 1:

THE CC NOZZLE ASSEMBLY



For example, plaster as the outer surface material and concrete as the core structural material may be co-extruded by the CC nozzle.

Early developments have been on a small scale but reveal the potential of CC in building construction through successful experimentation with (among others) clay, plaster and concrete. Our research team has also produced various geometrical shapes with a variety of materials (Figure 2). And we are currently creating and testing full-scale concrete wall sections for conformance to building codes (Figure 3). Future developments of the technology are projected in the following three research phases:

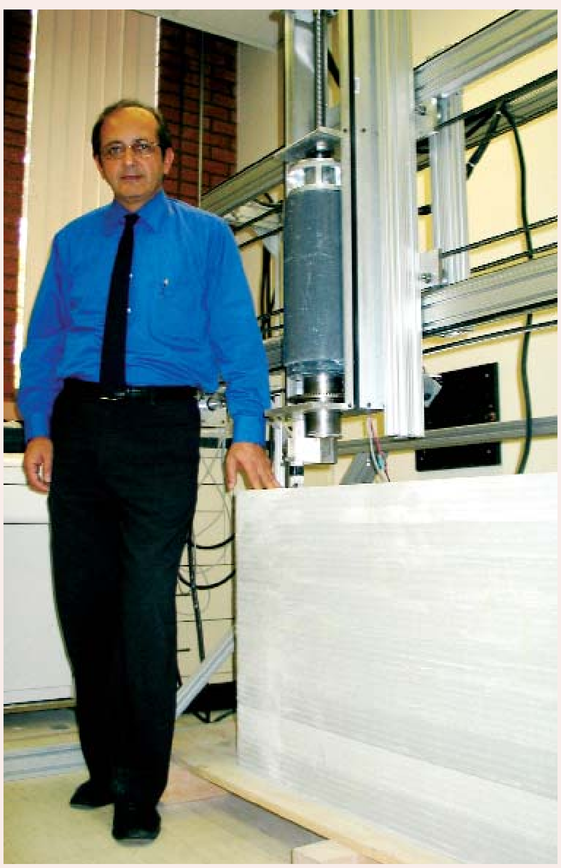
Phase I. The basic CC technology will be developed for automated construction of single-residence structures where a gantry system carrying the CC nozzle and other robotic arms moves on two parallel lanes installed at the

FIGURE 2:

SCALED OBJECTS MADE BY CC

FIGURE 3:

A FULL-SCALE CONCRETE WALL SECTION MADE BY CC



construction site (Figure 4). A single house or a colony of houses could easily be constructed in a single run. Integration of the CC machine with a support-beam picking and positioning arm could produce conventional structures, while organic form (e.g., adobe) structures could be built without external support elements by using shape features such as domes and vaults. In this phase, we also plan to develop both a smaller machine dedicated to construction of artistic structures as well as integrated automatic embedding of reinforcement materials.

Phase II. CC technology will be developed for construction of larger community and multi-residence structures. For apartment buildings, hospitals, schools and government buildings, for example, the overhead gantry platform (shown in yellow in Figure 5) could be extended above the width of the structures and equipped with multiple cross members each holding a CC nozzle assembly and a robotic manipulator (for beam installation, plumbing, etc.).

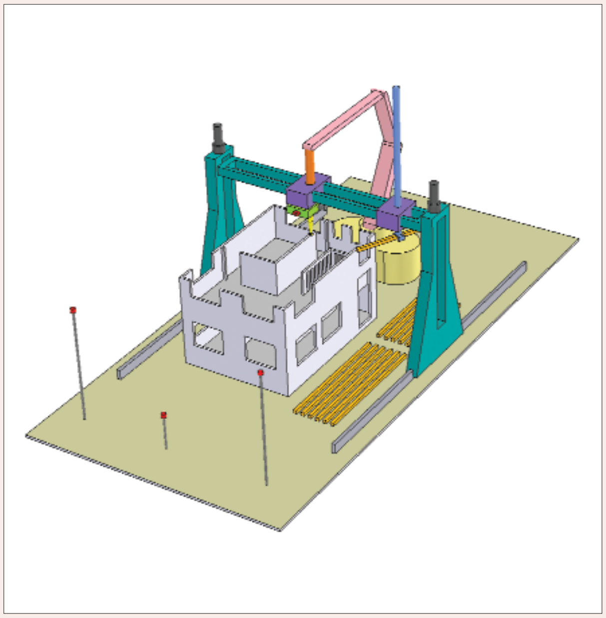
The integrated construction system in Phases II will also include automatic methods for tiling, plumbing, electrical and communication network wiring, and painting. Degussa AG and Maxit Group, the two largest producers of construction chemicals and materials, will conduct concurrent materials development research at their own expense.

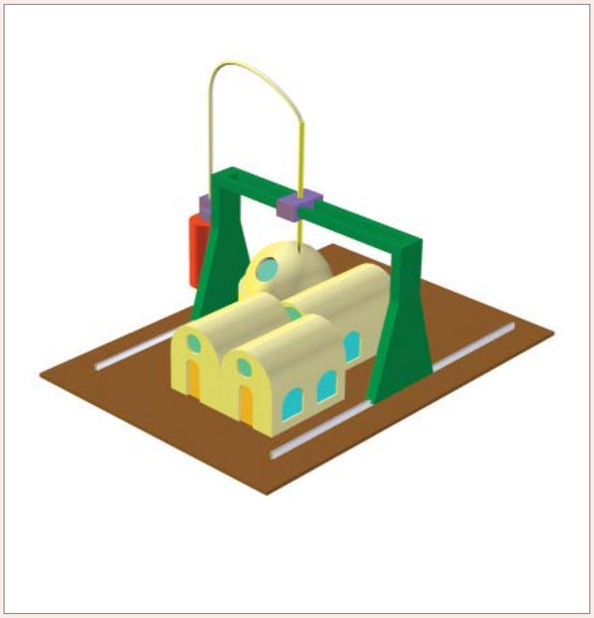
Phase III. In this phase, we will pursue the following implementation issues:

- Adaptation of CC for the construction of entire communities, including residential, public, and commercial building, as well as certain infra-structures such as pavements, landscapes, water reservoirs, etc. We will explore innovative designs, such as fractal communities with the flexibility of CC supports.
- While we will use the technology for low-income housing in underdeveloped countries almost immediately after its development, we will also address local building codes for commercial deployment of CC in the US.
- Due mainly to unprecedented speed of construction, CC will require attendant improvements in the construction inspection process. Therefore, we plan to develop advanced sensory systems and information technologies for real-time inspection and feedback to municipal computers overseeing ongoing CC construction activities at various locations
- Creation of necessary information technologies for construction project management for the new technology is crucial. Material procurement is especially important for CC, as all needed materials must become available at the site in a relatively short period of time. We will develop the needed project management software, communications systems, and supply-chain configuration for effective implementation of the technology on a major scale.

FIGURE 4:

CONSTRUCTION OF CONVENTIONAL AND ADOBE





USC's focus on finding solutions to complex urban problems is reflected in the CC research team's guiding principles:

- Maximum flexibility for architectural design. Buildings constructed with CC, though inexpensive, can be of high visual and aesthetic quality and can, therefore, provide a significant level of dignity to low-income residents.
- Ultimate friendliness to the environment due to wasteless operation and low energy usage.
- Simplicity of construction logistics and management.
- Dramatic impact on cost and speed (a 2000 sq. ft, two-story house may be built within a day)
- Adaptable application of in-situ (e.g. indigenous) materials. CC has an immediate application in emergency shelter construction.

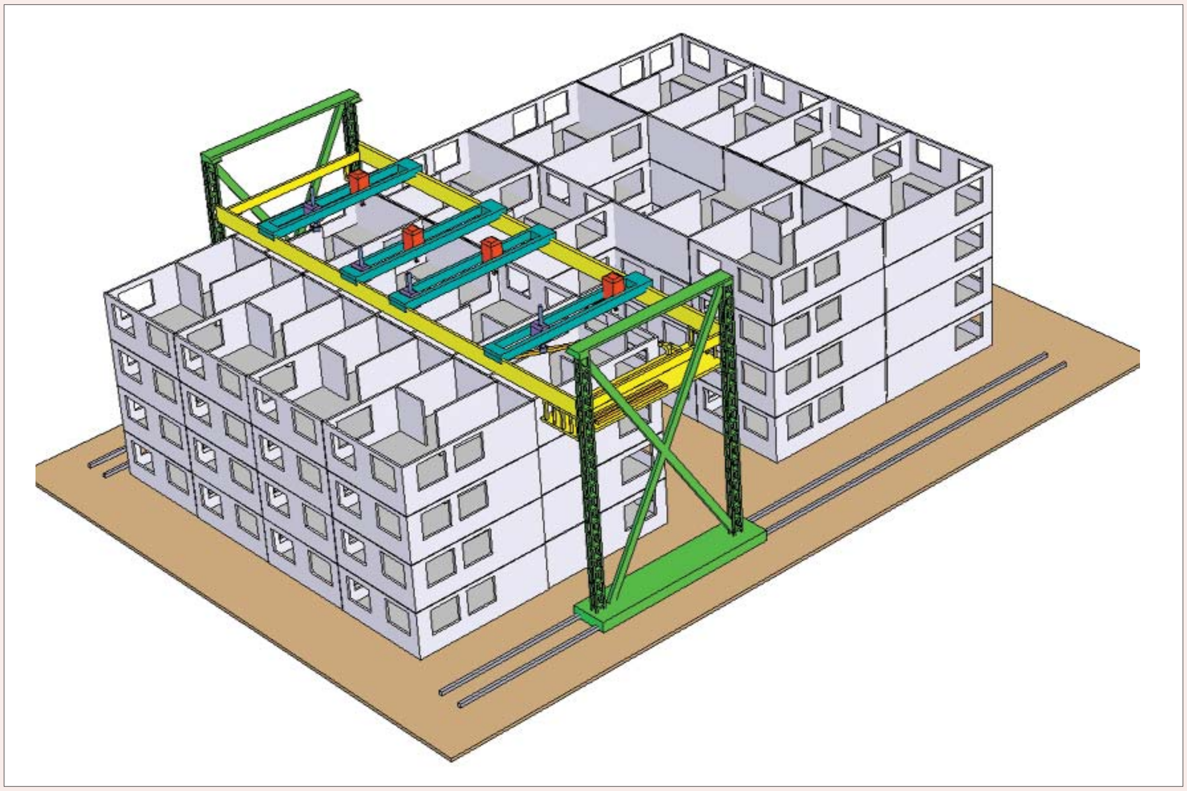
The USC research team has received several grants from prestigious funding agencies such as NSF, and has published award winning technical articles on the CC subject. Such attention, along with acclaimed national and international media coverage, indicates that USC has established itself as a premier research center for CC technology.

The USC team has established a plan to pursue several funding avenues to bring the CC technology to the actual implementation stage. It will continue to seek funding from public agencies for fundamental research in areas of technology as well as public policy (e.g., changes in assessing housing permits, inspection, construction employment needs, labor relations and union issues, urban and regional development, etc.) in conjunction with current and new PIs from the related schools within USC. The team also plans to work in conjunction with construction industry, construction equipment manufacturers, and construction materials companies. They will also seek the support of non-profit organizations such as Habitat for Humanity.

This policy briefing is available electronically at http://urban.usc.edu. Animations of the process and and several useful articles may be viewed at www.contourcrafting.org, or at the inventor's web site at www-rcf.usc.edu/~khoshnev.

FIGURE 5:

CC FOR MULTI-UNIT BUILDINGS



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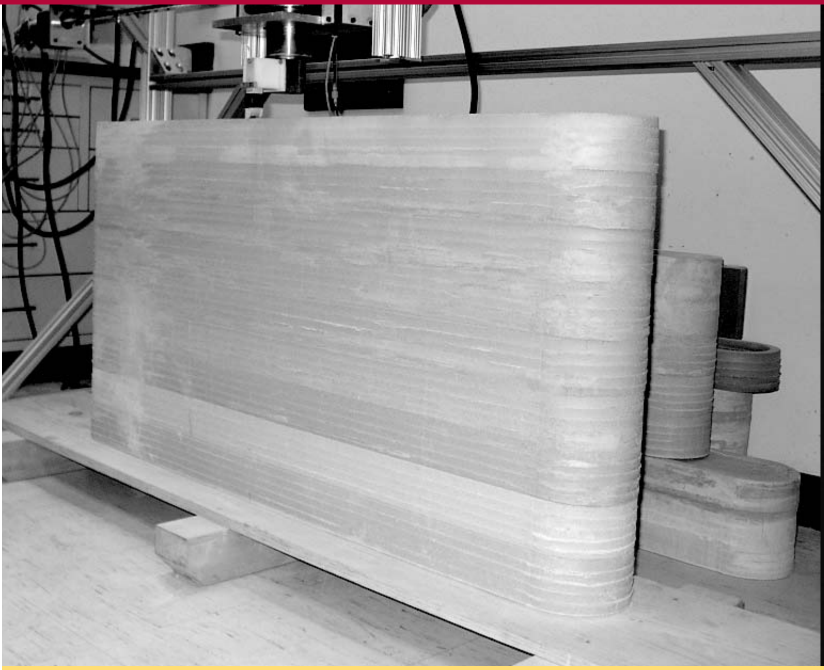

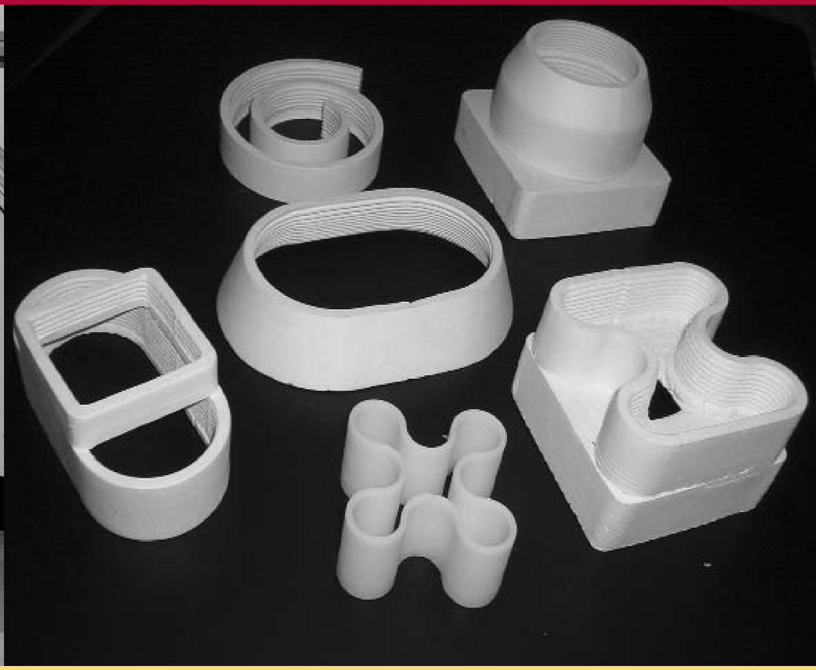

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